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Person Responsible: Mark Lively

Attachment NSTAR-JS-1-6(a)

Letter from Mr. Lively dated 2004 March 30 to Mr. Michael Hyrnick of FirstEnergy

2004 March 30

Mr. Michael S. Hyrnick
Managing Director, Business Development Group
FirstEnergy
76 South Main St., Suite 1600
Akron, Ohio 44308

Dear Mike:

I believe that you will find the enclosed "Pricing Uninstructed Deviations to Improve Reliability" relevant to FirstEnergy's response to the 2003 August 14 blackout investigations. You and I have talked about the problems that day associated with low voltage, reactive power, and the unresponsiveness of Independent Power Producers. This article deals with those concepts. Further, the reactive power portion may be particularly applicable to your dealing with PJM.

About three weeks ago, I got a question about how WOLF could address reactive power. The questioner had chaired a NERC committee to which I had made presentations on WOLF. His computer had crashed with my old WOLF material and he wanted to refresh his "library" particularly in regard to reactive power. He then asked about whether WOLF would work with LMCs such as PJM's to set a price for reactive power. The enclosed paper puts pricing reactive power in context with pricing uninstructed deviations by IPPs.

I look forward to talking with you again in the near future.

Yours truly,

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Mark B. Lively
Utility Economic Engineer

Pricing Uninstructed Deviations to Improve Reliability

By
Mark Lively
Utility Economic Engineers

Independent Power Producers (IPPs) need incentives to improve system reliability. IPPs now generally have an incentive to operate according to schedule, even when the system is crashing down around them. This became obvious to many people after the blackout of 2003 August 14, not only in regard to active power, but especially in regard to reactive power. The Lively WOLF mechanism can provide an incentive price that increase good uninstructed deviation and decreases bad uninstructed deviations, thus improving reliability. The incentive price can be considered to be liquidated damages for uninstructed deviations.

Introduction

Before restructuring, electric utilities provided aid to their neighboring utilities in trouble. Sometimes the aid was in the form of high priced emergency power. Sometimes the aid was in the form of short term loans of power, which the receiving utility would "return-in-kind" at some subsequent period. Since the return of power is never quite under the same conditions as the initial delivery of power, I began developing Wide Open Load Following (WOLF) as a way to set a price for unscheduled deliveries of electricity.

Twenty years ago I believed the unscheduled delivery of power from one utility to another was a major problem and was getting worse. I also believed that the issue was not just one utility borrowing power from its neighbors. Sometimes a utility would instead borrow the use of a power line. Borrowing a power line is one way to describe the concept of parallel path flow and other forms of loop flow.

I felt that the lack of a way to price unscheduled flows of power between utilities would hinder the development of IPPs, as is shown in the title of my first article "Tie Riding Freeloaders--The True Impediment to Transmission Access," *Public Utilities Fortnightly*, 1989 December 21. That article was my first public exposition of WOLF as a way to pay for unscheduled flow of electricity.

Fifteen years ago I felt that utilities would be reluctant to interconnect with IPPs. That reluctance was due to the utilities having insufficient opportunities to obtain revenue for the services they would provide directly or indirectly to IPPs. Services are provided indirectly by the assistance given to utilities that host IPPs within their footprint. I believe that the issue still exists today and is getting worse.

The comments about the 2003 August 14 blackout show the current concern about the lack of pricing for unscheduled active power flows. The issue list now includes

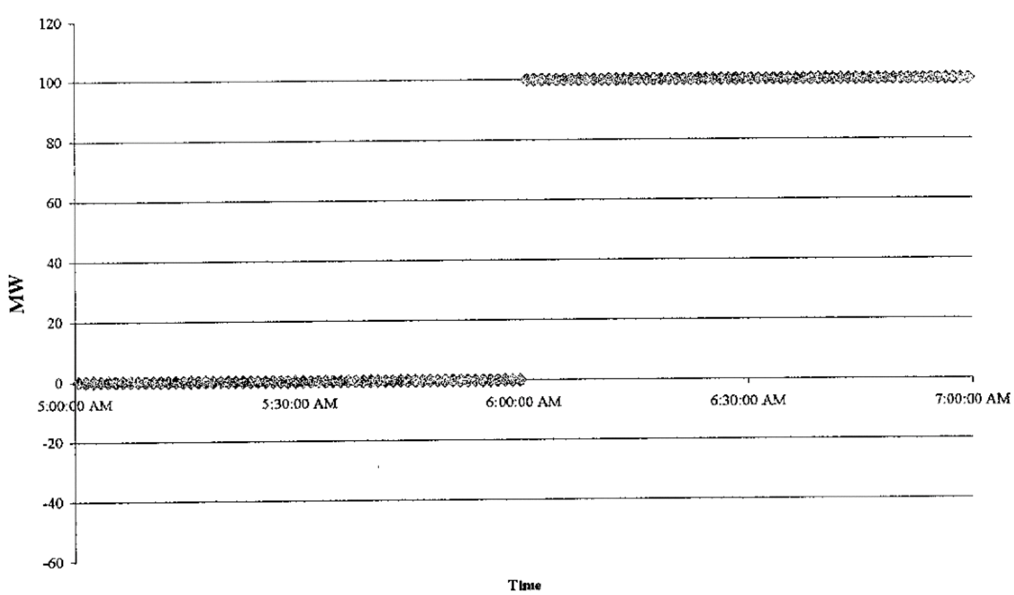
- Uninstructed deviations between a utility and the IPPs in its footprint
- Reactive generation and consumption by IPPs
- Unscheduled reactive power flows between utilities

WOLF pricing concepts can be used to encourage IPPs to help the local utility keep its lights on by favorably pricing good uninstructed deviations. WOLF would also set prices that would discourage IPPs from bad uninstructed deviations. Though WOLF is mostly thought of in regard to active power, the concept can be extended to reactive power.

Scheduling IPPs

Electricity must be generated as it is consumed. The strong daytime demand for electricity has led to the development of a standard sixteen (16) hour contract from 6:00 AM to 10:00 PM. This standard contract requires the delivery of the same amount of energy during each of the sixteen (16) hours. Further, the standard contract requires the delivery of the same amount of power during each instant of those sixteen (16) hours.

IPP Schedule
Figure 1



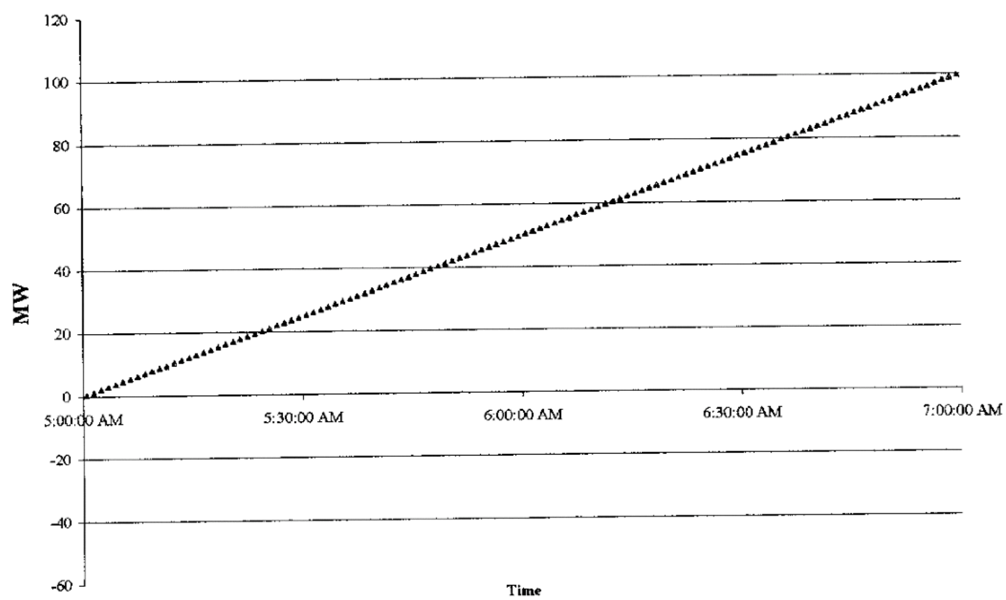
Of particular interest to the electric industry are the periods of startup and shutdown. Figure 1 shows the scheduled delivery for a 100 MW contract for the two (2) hours between 5:00 AM and 7:00 AM with a granularity of one (1) minute. All of the data points are identified by the half minute. At 6:00 AM, the schedule goes from 0 MW to

100 MW. Thus, the last zero value is for 5:59:30 AM and the first value of 100 MW is for 6:00:30 AM.

Though we flip a switch in our homes and offices and have all of our lights on in a few seconds, large generating plants don't respond so quickly. Instead a generator will slowly ramp up from zero to full load, perhaps as is illustrated in Figure 2. In the example in Figure 2, the ramping extends over the full two hour period of the graph, substantially longer than often occurs for a 100 MW generator. It should be noted that larger generators can indeed take several hours to ramp from zero to full load, not just the two (2) hours illustrated by Figure 2. Again, the data points in Figure 2 are spaced one minute apart on the half minute.

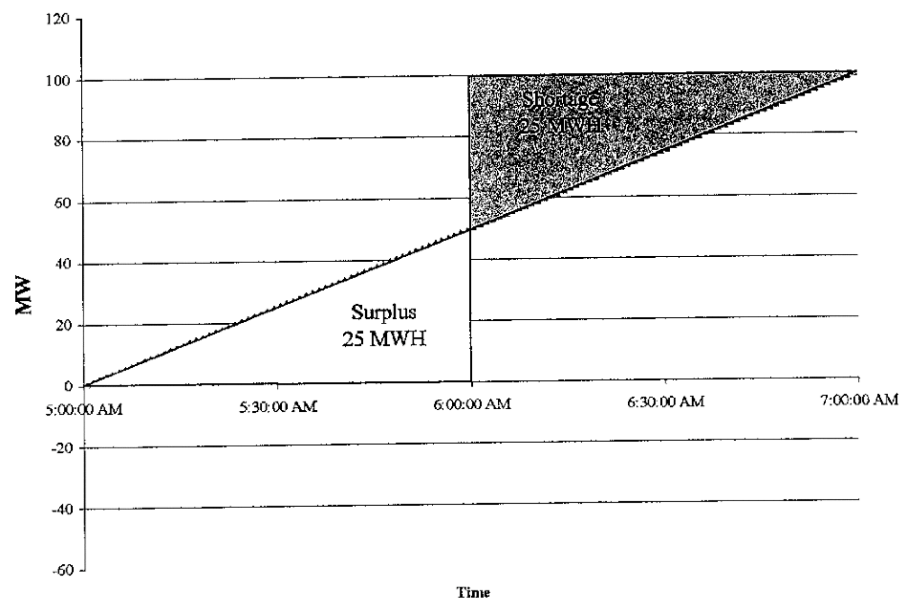
IPP Generation

Figure 2



Combining Figure 1 and Figure 2 produces Figure 3. The difference between the data points have been painted to show an area. Based on the height of the graph being power and the width of the graph being time, the highlighted area is energy. Figure 3 illustrates the surplus energy that the IPP delivers to the grid during the hour from 5:00 AM to 6:00 AM, as well as the shortage that exists during the hour from 6:00 AM to 7:00 AM. During the hour before the start of the schedule, the IPP delivers 25 MWH to the grid that is over and above its obligation. During the hour after the start of the schedule, the IPP delivers 75 MWH to the grid, 25 MWH short of its obligation. Under the concept of "payback-in-kind", the IPP and its utility host would be even after this two hour period.

IPP Imbalance
Figure 3

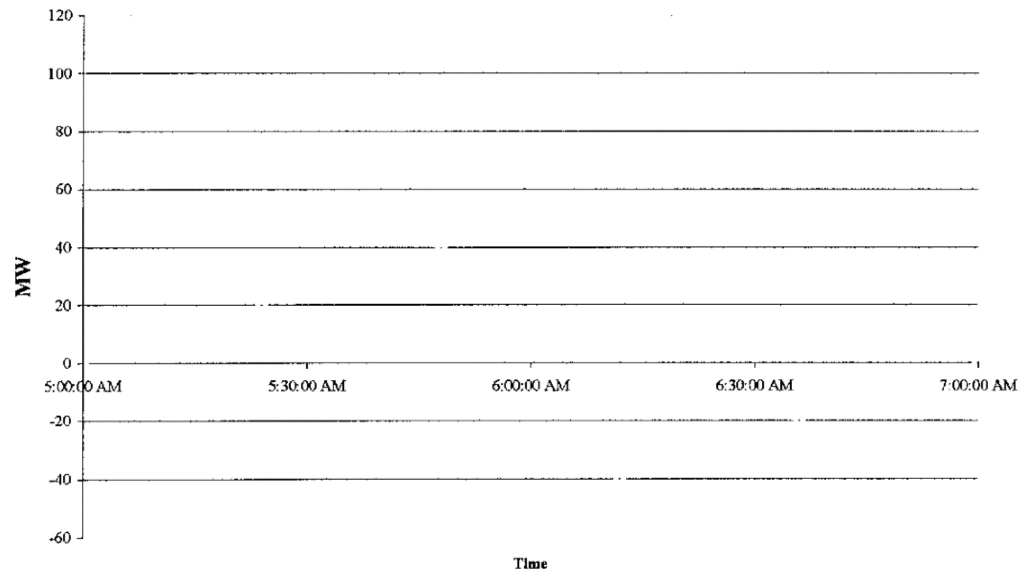


Under the utility concept of a return-in-kind, the IPP would incur no penalty for having a surplus during the first hour of Figure 3 that balanced the shortage during the second hour of figure 3. Utilities generally did not complain about this practice prior to the restructuring of the industry. Now utilities are finding that they are increasingly burdened by these unscheduled flows of electricity, and that these unscheduled flows are costly.

Effect on Utilities

The inequity of trying to trade a shortage for a surplus is best demonstrated if the IPP is in the footprint of one utility and has the contract with a second utility. The IPP and the first utility will have a schedule that looks like Figure 1, as will the first utility and the second utility. The first utility must then adjust its own generation to achieve the almost instantaneous ramp shown in Figure 1. Without an adjustment of its own generating level, the first utility would have the Area Control Error shown in Figure 4. The Area Control Error ramps up over two (2) hours. The ramp up coincides with the ramp up of the IPP generation, except for the sudden drop when the schedule begins at 6:00 AM. Again, the data points are for one minute periods centered on the half minute.

Utility Area Control Error (ACE)
Figure 4



WOLF uses physical measurements of shortages and surpluses to set the price for unscheduled flows of electricity. For a utility or for an Independent System Operator (ISO), ACE is the appropriate physical measurement of shortage or surplus for setting the price of active power. Currently, ACE is calculated every two to four seconds by each utility and by each ISO in North America. The granularity of the graphs used in this paper is one minute, or 15 to30 times the granularity of the ACE calculation. Thus, though the industry often thinks about hourly measurements, minute by minute measurements are possible since a minute is much longer than the time frame used for ACE.

The WOLF pricing concept is presented graphically in Figure 5. WOLF increases or decreases the price exponentially by the size of ACE and whether ACE is negative or positive. In the example presented in Figure 5, the base price of uninstructed deviation is $40.00/MWH. The base price is the price paid for surplus generation when ACE is zero. It is also the price charged for shortages under the same circumstance. In the example presented in Figure 5, the doubling constant is 50 MW. When ACE is positive by 50 MW, the price is half of the base price, or $20.00/MWH in the example. Conversely, when ACE is negative by 50 MW, the price is twice the base price, or $80.00/MWH in the example.

Figure 5 has a different horizontal axis than do Figures 1 through 4. The earlier figures had a horizontal axis identified by time, with one minute increments, since they represented minute by minute measurements, or measurements over even shorter time periods that were then aggregated by one minute periods. In contrast, Figure 5 is a translation of ACE into a price.

Pricing Chart
Figure 5

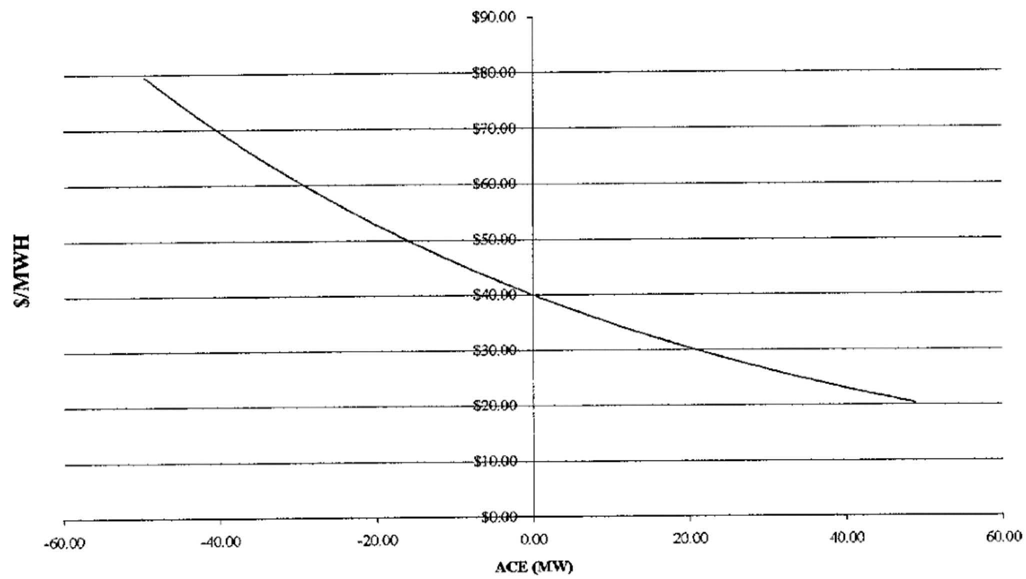


Figure 5 is calculated using the formula

$$\text{Price (\$/MWH)} = \$40/\text{MWH} * 2^{-\text{ACE}/50\ \text{MW}} \qquad \text{Equation 1}$$

ACE can be any real value. As stated previously, ACE is calculated every two to four seconds by the utility. ACE is the unscheduled flow of electricity out of the utility as biased by the utility's frequency obligation. Figure 4 was created using two assumptions

- The utility has zero imbalance between its other generation sources and other load obligations. Thus, the only unscheduled flow out of the utility is the IPPs uninstructed deliveries
- There is zero frequency error during the time. Thus, there is no frequency bias in the calculation of ACE.

Both of these assumptions are unrealistic but are used initially to simplify the example. For instance, the utility will attempt to reduce the ACE caused by the IPP uninstructed deviation. Further, the imbalance and frequency error sometimes seem as if they have a random noise component.

Payment for Uninstructed Deviation

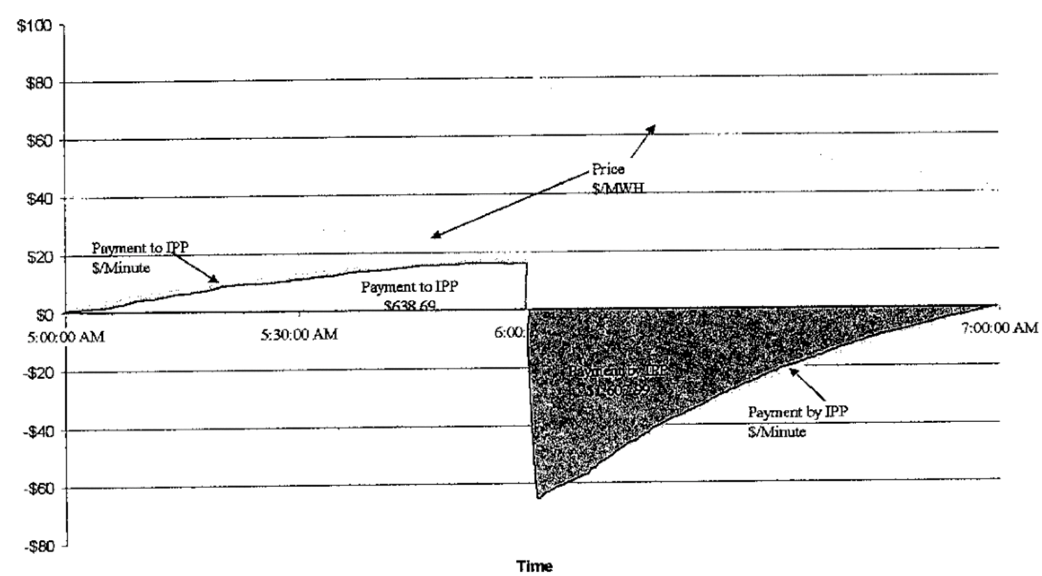
The curves in Figures 3, 4, and 5 can be combined to develop the payment to and from the IPP for its uninstructed deviations, which develop Figure 6.

First, the minute by minute ACE values in Figure 4 are priced, either with the curve in Figure 5 or with the formula in Equation 1. This procedure produces the prices shown in Figure 6 in $/MWH. The prices in the first hour range from $39.77/MWH to $20.12/MWH. During the second hour the prices range from $78.93/MWH to $40.23/MWH. The prices are generally toward the top of Figure 6. Just as the ACE values in Figure 4 are discrete value, so are the prices in Figure 6.

Second, the minute by minute IPP imbalances in Figure 3 are evaluated at these minute by minute prices in Figure 6. Figure 3 shows the imbalances in MW, so the payments are the imbalances times the price in $/MWH divided by 60 minutes/hour. For instance, during the minute centered around 5:48:30 AM, the IPP generated 40.4167 MW, or 0.673611 MWH. The WOLF price was $22.84/MWH and the payment was $15.39.

The colored areas of Figure 6 represent the total payments for the imbalances. Notice that the payment to the IPP during the first hour is substantially less the than payment by the IPP during the second hour. The difference is the result of the imbalances during the second hour having a unit value that is much higher price than during the first hour. The difference in unit value is due to the corresponding magnitude of ACE.

IPP Payments
Figure 6

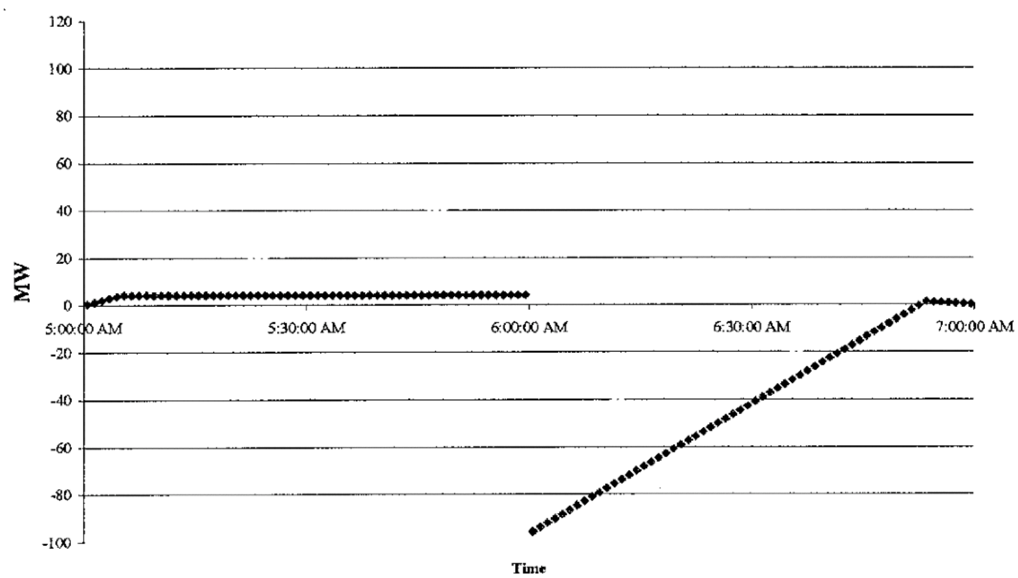


Better ACE Control

In practice, a utility will not control its ACE in the manner presented in Figure 4. There ACE would have been zero except for the uninstructed deviation of an IPP within its footprint. Normally, the utility will attempt to zero its ACE by including the effect of uninstructed deviations of the IPP within its footprint. One way that a utility might control its ACE is demonstrated in Figure 7.

The example in Figure 7 begins with the utility responding to the ACE imbalance with a five minute lag. Once the utility sees that its ACE is positive, the utility will begin decreasing its internal generation, reducing ACE. In this example, the utility starts decreasing generation five minutes after the IPP starts generating and then matches the IPP's ramping. Again, there is a five minute lag. The sudden start of the schedule at 6:00 AM causes ACE to zoom greatly negative. The utility then attempts to increase generation to zero out the negative ACE. In this example, the ramp rate of the utility is 1 MW/minute. For reference purposes, Figure 7 also includes the ACE shown in Figure 4.

Adjusted Area Control Error (ACE)
Figure 7

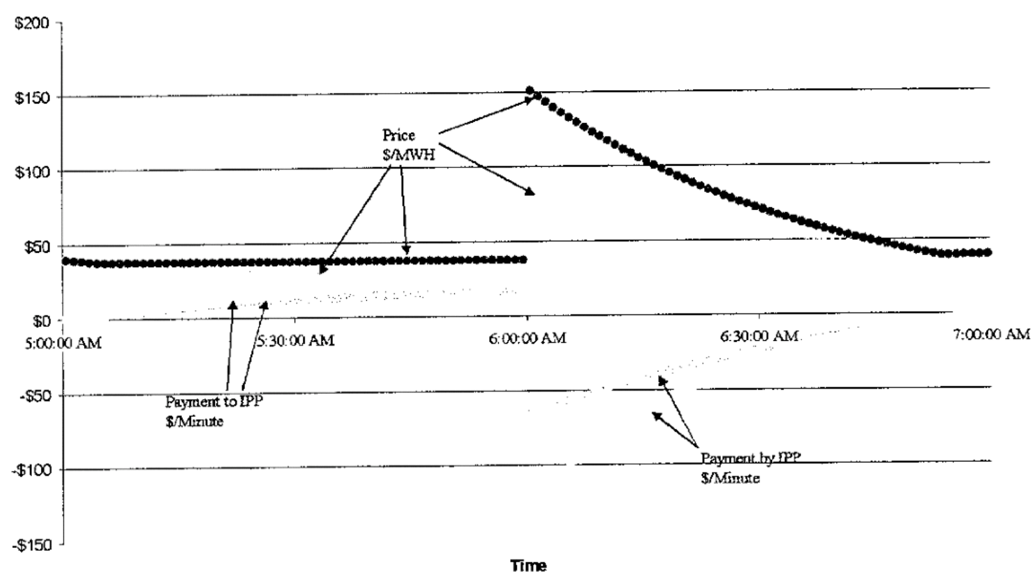


The procedure used to produce Figure 6 can now be used to price the uninstructed deviation shown in Figure 3. But this time, the utility is attempting to control its ACE more closely as the IPP is ramping up. The pricing result is shown in Figure 8. The data from Figure 6 are repeated for reference purposes.

In regard to the prices shown in Figure 8, once the utility begins responding to its ACE imbalance at 5:05 AM, the price for imbalances stops declining and stays constant until 6:00 AM. When the schedule begins at 6:00 AM, the price abruptly increases even more than it did previously. The abrupt increase is due to the non-linear nature of the WOLF price.

In regard to the payments shown in Figure 8, the IPP receives more for its surplus during the first hour, but also pays more for the shortage that occurred during the second hour. The difference between the two approaches the utility takes to controlling ACE is that the IPP would have paid a net of $969.29 in the first example and a net of $1,498.53 in the second example. In both examples, the IPP had a 25 MWH surplus during the first hour and a 25 MWH shortage during the second hour.

IPP Payments
Figure 8



Self Correcting WOLF Price

A utility will have more than one IPP for which it has uninstructed deviations, perhaps dozens or even hundreds. The latter concept of hundreds of IPPs with uninstructed deviations is consistent with the many distributed generators on the network. Since distributed generators are often smaller than 1 MW, most will not have schedules with the utility and will only have uninstructed deviations, at least if one counts their entire production as uninstructed deviations. For IPPs (including distributed generators) that have some associated load, the uninstructed deviations can be positive or negative. In that regard these small distributed generators can be viewed in the same light as the IPP under discussion above.

The utility has an interest in optimizing its operating results, generally minimizing its costs or maximizing its revenue. In the context of payments for uninstructed deviations, the utility will want the price to be about equal to its marginal cost of production, whether the utility is buying uninstructed deviations or is selling uninstructed deviations. And if the utility does indeed have substantial distributed generation, the utility will often not know the amount of distributed generation being priced at WOLF until substantially after the fact. Thus, it will not know concurrently whether to bias the WOLF price high because it is a net seller of uninstructed generation during that minute or to bias the WOLF price low because it is a net buyer of uninstructed generation during that minute.

The utility can indeed manipulate WOLF in its production of the price for uninstructed deviation. The incentive is for the utility to move the WOLF price toward its marginal cost of production, especially when the utility does not know whether the uninstructed deviation is a net purchase or a net sale during each minute.

- When the utility has a marginal cost of production that is greater than the WOLF price, the utility can reduce its net cost by decreasing production.
    - The utility buys electricity at the WOLF price instead of incurring its own marginal cost.
    - The action of decreasing production will result in ACE becoming lower.
    - The reduction in ACE will in turn raise the WOLF price.

  The utility should reduce its production until its marginal cost is approaching the WOLF price.

- When the utility has a marginal cost of production that is less than the WOLF, the utility can reduce its net cost by increasing production.
    - The utility produces more electricity at its marginal cost instead of buying electricity at the WOLF price.
    - The action of increasing production will result in ACE become larger.
    - The increase in ACE will in turn lower the WOLF price.

  The utility should increase its production until its marginal is approaching the WOLF price.

The utility should operate its generators so that marginal cost approaches the WOLF price, not so that the utility's marginal cost is equal the WOLF price. The utility has reliability obligations to be able to respond to sudden changes in load and generation. This obligation is consistent with the utility attempting to approach the WOLF price with its marginal cost of generation, whether from above or below, instead of equaling the WOLF price. Further, the true economic optimum operating point results in marginal cost equaling marginal revenue, and marginal revenue is slightly different from the WOLF price.

WOLF uses system measurements to set the price for unscheduled flows of electricity. In Equation 1 and in Figure 5, the WOLF price varied with a single measurement, the utility's Area Control Error (ACE). WOLF also has a procedure to use various measurements of time error to set the base price of $40/MWH. However, when there is a way to establish a market price for energy prior to the beginning of each time period, then WOLF can use that established market price as the base price, the $40/MWH used in these examples.

Reactive Power

The 2003 August 14 blackout made many Americans and Canadians aware of the concept of reactive power, but not much about that concept. What people did learn is that reactive power also has a major influence on voltage.

Reactive power is a phenomenon associated with alternating current. Reactive power is the portion of the power flow that will turn on a motor. That is, reactive power changes a piece of iron into a magnet. With ac power, the reactive power flows in and out twice a cycle, where a cycle is about $1/60^{th}$ of a second. During part of the cycle, the reactive power can be thought of as turning the motor into a North/South magnet. Then the reactive power flows out and the magnet is turned off. During the next part of the cycle, the reactive power turns the rotor into a South/North magnet. Notice the difference in orientation. Then the reactive power flows out again and the magnet is again turned off. In contrast, active power is the portion of the power flow that will cause the motor to turn and do work. Total power is the sum of active power and reactive power.

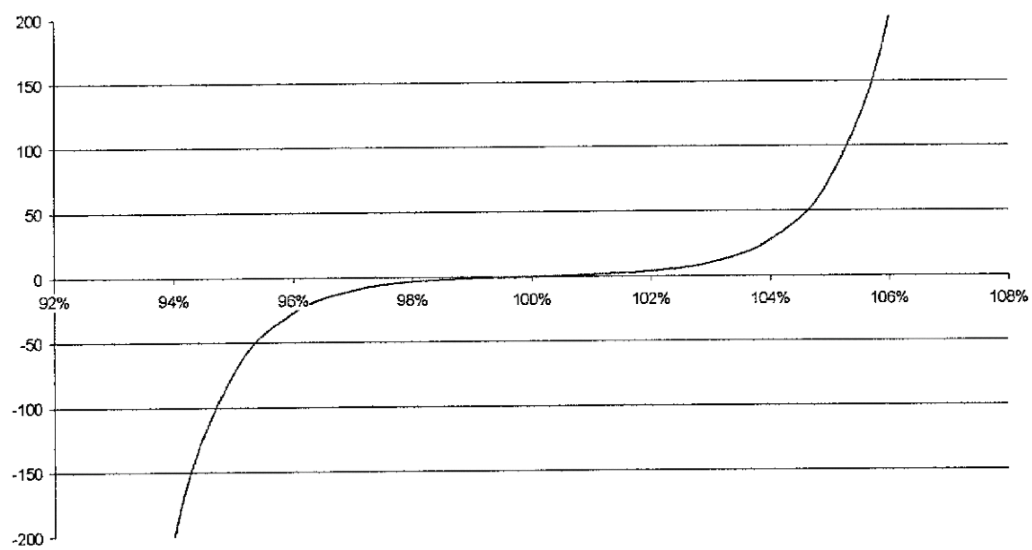
Motors need lagging ac power to operate. Just as an ac current goes up and down 60 times a second, so does the ac voltage. When the change in the current is slightly behind the change in the voltage, or is lagging the change in the voltage, engineers say that the power factor is lagging. Lagging power will cause the voltage to decline nearby. Thus, motors, with a need for lagging power, can cause the voltage to be lower than is desirable. To counteract the low voltages caused by motors, capacitors are often installed in substations, on transmission lines, and in industrial plants. Further, generators have the ability to operate with either a leading or a lagging power factor.

WOLF prices reactive power based on the price for active power and the voltage level. When the voltage is at nominal, there is no charge for reactive power. When the voltage is above nominal, WOLF charges leading reactive power and pays lagging reactive power. When the voltage is below nominal, WOLF charges lagging reactive power and pays leading reactive power.

A convenient scaling function for pricing lagging reactive power is the hyperbolic sine, an engineering function that has a slight slope through zero and then rapidly increases in magnitude, as is shown in Figure 9. Since the hyperbolic sine is symmetric about (0,0), Figure 9 has a voltage offset of 100%. Thus, the curve is centered about nominal voltage.

At the nominal voltage the payment is zero. Further, to get the curve to begin its rapid increase in the neighborhood of +/- 3% of nominal voltage, the voltage has been scaled by 100.

Hyperbolic Sine
With Voltage Scaled by 100 and Offset To 100%
Figure 9



Pursuant to a pricing curve such as Figure 9, all reactive energy would be priced. When the voltage is near nominal, that is, very close to 100% of standard voltage, the price for reactive energy would be miniscule. For instance, if the vertical scaling is $/RKVAH, at +/- 1%, the price is $1.17/RKVAH; at +/- 2%, the price is $3.63/RKVAH; at +/- 3%, the price is $10.03/RKVAH; at +/- 4%, the price is $27.30/RKVAH; and at +/- 5%, the price is $74.20/RKVAH.

Conclusion

IPPs are generally penalized for deviating from their scheduled production. Similarly, loads are sometimes penalized for varying from the level of their committed purchases. The penalties for IPPs are often high prices for any underproduction and low prices for overproduction. Such a pricing scheme prevents IPPs from operating in a manner that assists the system operator in keeping the lights on, since few market based entities want to pay a penalty to help the system.

WOLF provides system operators with prices that encourage good deviations from schedule and discourages bad deviations from schedule. The goodness or badness of the deviation from schedule is based on whether the deviation can be deemed to be making operating conditions better or worse.

- For active power, the operating condition is Area Control Error (ACE) or system frequency, which is a component of ACE.
    - Positive ACE results in low prices. Low prices are seen as punishment for IPPs that over-generate and contribute to the positive ACE. Conversely, low prices are seen as rewards for IPPs that under-generate and whose under-generation kept the positive ACE from being even larger.
    - Negative ACE results in high prices. High prices are seen as punishment for IPPs that under-generate and contribute to the negative ACE. Conversely, high prices are seen as rewards for IPPs that over-generate and whose over-generation kept the negative ACE from being even larger.

  The scaling constant of a doubling of the price for every 50 MW decrease in ACE needs to be adjusted to reflect the size of the utility.
- For reactive power, the operating condition is local voltage.
    - High voltages result in positive prices for lagging power and negative prices for leading prices.
    - Low voltages result in positive prices for leading power and negative prices for lagging power.

  Additional scaling of the reactive power portion of WOLF pricing needs to be field tested.